Synthetic Aperture Sonar Forward Modeling and Inversion

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LONG-TERM GOALS

Current and future high-resolution MCM systems such as Synthetic Aperture Sonar are actively being developed. Unfortunately, this development is proceeding in many cases without a solid understanding of how environmental effects might degrade performance or how data inversion can be used to extract information about the environment. While these systems have been largely successful in achieving their goals of producing high-resolution imagery (on the order of square centimeters), there has been little effort in linking scattering physics to both the mean levels and statistics of the resulting sonar returns seen in the images. This type of knowledge is crucial for producing both realistic forward and inverse models.

The long-term goals of the present research are to develop and validate physics-based models and inversion tools relevant to current and future synthetic aperture sonar systems. The influence of the properties of the boundaries to the scattered envelope statistics will be examined in detail as will methods to invert system data for environmental parameters. This study will yield an improved understanding of the link between environmental parameters and system factors which contribute to SAS image statistics, as well as models and methods for characterizing, predicting and mitigating environmental effects. This effort may lead to improved methods for environmental characterization (i.e., 'through-the-sensor' inversion of seafloor properties), have direct application to performance prediction, and possibly provide guidance for adaptive strategies for speckle reduction based on the operational environment.

OBJECTIVES

The importance of the present work lies in the ability to link SAS image statistics to measurable environmental properties such as seafloor roughness. In conjunction with sonar system parameters, this link will provide the foundation necessary for solving several important problems related to the detection of targets with SAS. The direct link between system and environmental parameters via scattering models to the statistical distributions will allow: performance prediction for different systems based on environmental properties, extrapolation of performance to other systems/bandwidths, and optimization of system parameters such as frequency/bandwidth to the local environment.

Report Documentation Page

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1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
2012	**N/A**	**-**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Synthetic Aperture Sonar Forward Modeling and Inversion	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	8. PERFORMING ORGANIZATION REPORT NUMBER
The Pennsylvania State University Applied Research Laboratory P.O. Box 30 State College, PA 16804-0030	

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE	**SAR**	**7**	
unclassified	**unclassified**	**unclassified**			

Concisely the proposed objectives are:

1. Examine relationships of acoustic scattering properties (sediment interface and possibly volume for low-frequency systems) to SAS mean levels and statistics;

2. Develop predictive physics-based forward models of mean levels and statistics relevant to SAS;

3. Develop inversion tools for estimating seafloor properties based on forward models;

4. Validate forward models and inversion results against at-sea experimental data.

APPROACH

Work has been conducted recently at the Applied Research Laboratory – Penn State University (ARL-PSU) to characterize and model high-frequency scattered amplitude statistics of SAS imagery as a function of resolution, relationship to correlated seafloor structures (ripples) and propagation conditions. Work conducted with Peter Gough at the University of Canterbury in Christchurch, New Zealand, has also shown promising initial results on the possibility of inverting SAS data for large scale 2-dimensional height fields. As a follow on, the proposed research program intends to increase our understanding of how acoustic scattering processes impact SAS data in terms of both mean levels and statistics. Knowledge gained will be included in models aimed at aiding in the prediction of environmental effects on current and future MCM acoustic systems and on inversion for environmental parameters. These goals will be achieved through a close association with current PIs and projects being performed by the NSWC-Panama City. Model development will be guided by feedback from real data collected by the NSWC-Panama City and also from collaborative work with the Norwegian Defence Research Establishment (FFI).

Initial focus will be on acoustic characterization and modeling of speckle in images of ripple sandy seafloors and we will later look at more complicated scattering scenarios (e.g. seagrasses, rocky outcrops, and possibly sediment volume effects). Collaboration with the NSWC-PCD will facilitate use of their quality SAS data and results will be fed back into their program. Inversion of component forward models will also be a main priority.

WORK COMPLETED

A variety of topics were investigated in FY2012, some a completion of work begun in FY10 and FY11. Work continued this year with graduate student Derek Olson on using SAS systems to characterize rocky outcrops. This year's work also included a continuation of a study on understanding the effects of random roughness on SAS texture statistics. This study involved the use of data provided by the NATO Undersea Research Centre. With graduate student Dan Brown we continued our investigation into SAS speckle statistics for very wideband systems (those with a bandwidth to center frequency greater than 1. Models of speckle for these types of systems showed that speckle will still be Rayleigh distributed for cases when the theoretical resolution becomes smaller than a wavelengh. Data from the recent pond experiment was also used to help us clarify this finding and although not conclusive, did not contradict the model results.

Our work this year also included the completion of an analysis of experimental data on the temporal coherence of acoustic scattering in the context of SAS coherent change detection and the use of the

results of this analysis in the devlopment of methods for simulating temporal changes in SAS images between repeat passes. In the analysis of experimental data, acoustic data and seafloor roughness ground truth data collected during the ONR sponsored Sediment Acoustics Experiment '04 (SAX04) experiment were used to estimate the decorrelation of acoustic signals scattered from the seafloor due to changes in the shape of the seafloor interface. Small-roughness perturbation-theory was used to relate decorrelation of seafloor roughness spectral estimates to the decorrelation of scattered acoustic signals. The effect of the environment on temporal coherence for a given site was quantified in a single parameter, the diffusion coeffeicient which indicates how fast the environment changes at a given location. This parameter could serve as a possible metric for the performance of CCD for different sites.

A portion of the SAS data analyzed this year was collected in April, 2011 during a joint field experiment that took place near Larvik, Norway, as part of a collaborative work with the Norwegian Defence Research Establishment (FFI). As virtually no information exists on scattering from rock outcrops, we have worked on obtaining quantitative measurements of acoustic properties, such as the scattering cross-section, using SAS. The FFI SAS system operated at a center frequency of 100 kHz, has a bandwidth of 30 kHz and was operated from the HUGIN Autonomous Underwater Vehicle (AUV). To take advantage of the high-resolution capabilities of this SAS data and still obtain physically meaningful results, an 'effective' combined source strength and receiver sensitivity was found by comparing the scattering cross-section from a smooth, featureless rock imaged with the SAS system with estimates made with the small slope approximation using known geo-acoustic parameters. Local slopes on the rock were estimated with the high-resolution interferometric bathymetry available with the HISAS system. Figure 1 shows the rock and model fit used to estimate the effective combined source strength and receive sensitivity. Sample scattering strength estimates for rock determined using the 'calibrated' SAS system will be shown in the next section.

RESULTS

From the Larvik, Norway, trial, an image of a featureless, flat rock (Fig. 2) was used to calculate a combined source strength and receiver sensitivity of 106 dB re 1 V^2m^2. This level was used to invert for the normalized squared pressure of the backscatter from exposed rock outcroppings. The scattering strength from rocks was extracted from the normalized pressure squared by selecting a region and averaging in cross-range, and then averaging over one degree increments. To measure the scattering strength from a rock surface, the mean slope was known from the high-resolution interferometric bathymetry so that the global grazing angle of the ideal mean seafloor could be mapped to the local grazing angle of the rock. After system calibration, scattering strengths were found to range from -5 dB to -35 dB over grazing angles of 0 to 90 degrees (yielding an approximate Lambert parameter of approximately -15 dB). Figure 3 displays sample scattering strength data taken from a smooth portion of a granite rock outcrop (striated) and a rough portion (plucked). The smooth side is well behaved but doesn't match the small slope approximation while the rough side matches a Lambertian curve and is much more variable.
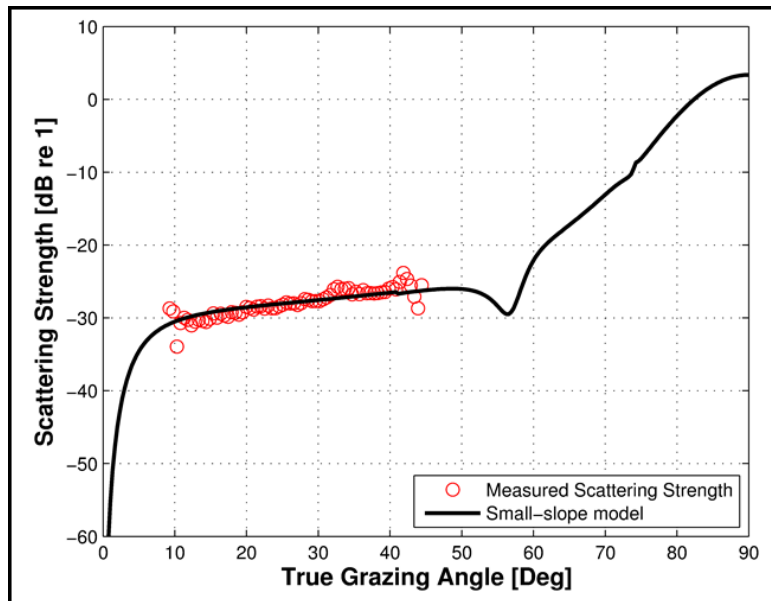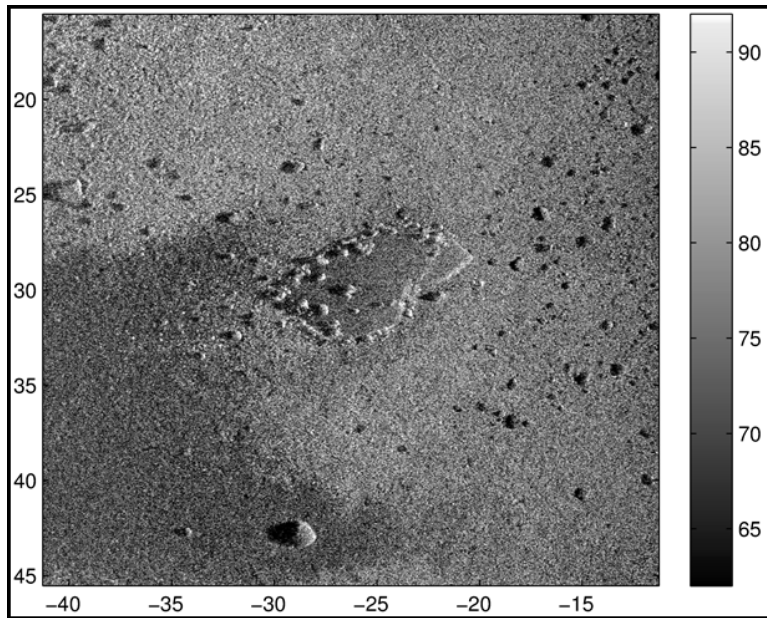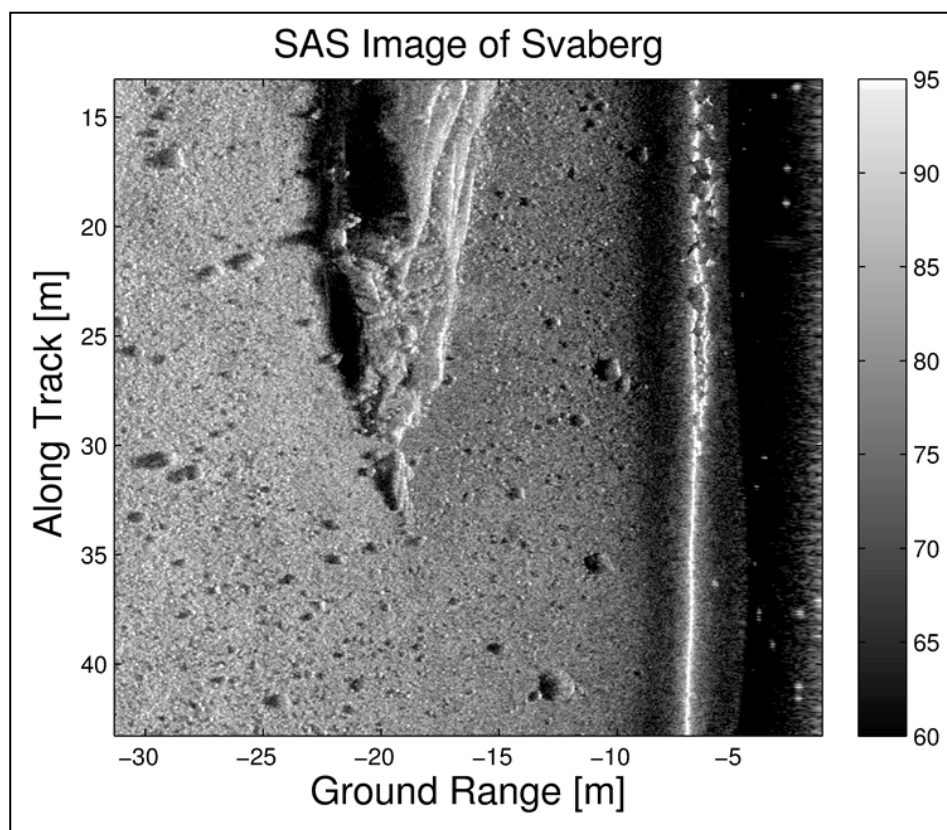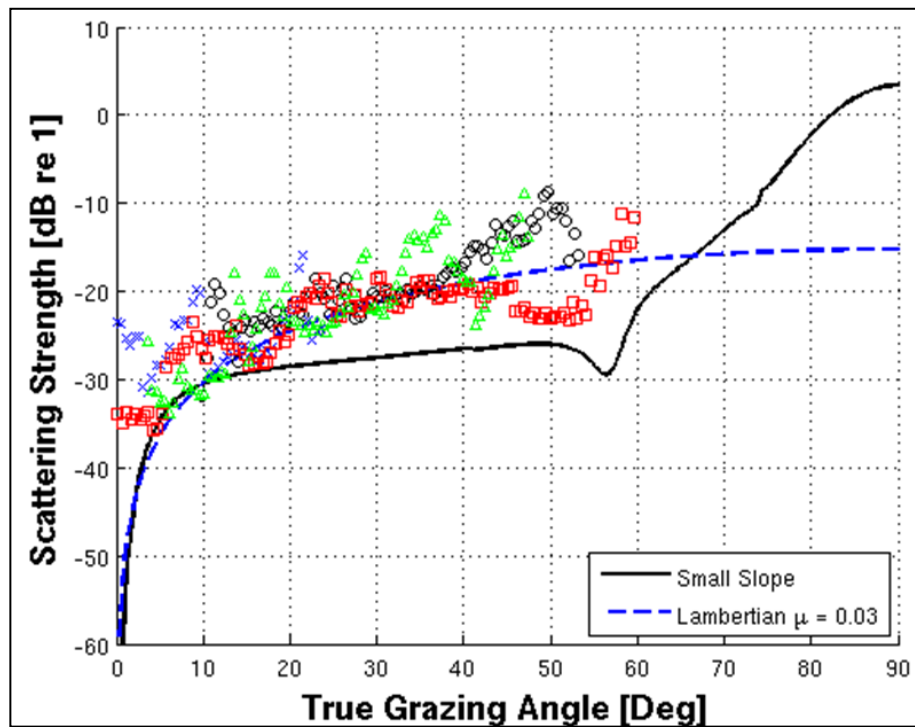
Figure 1

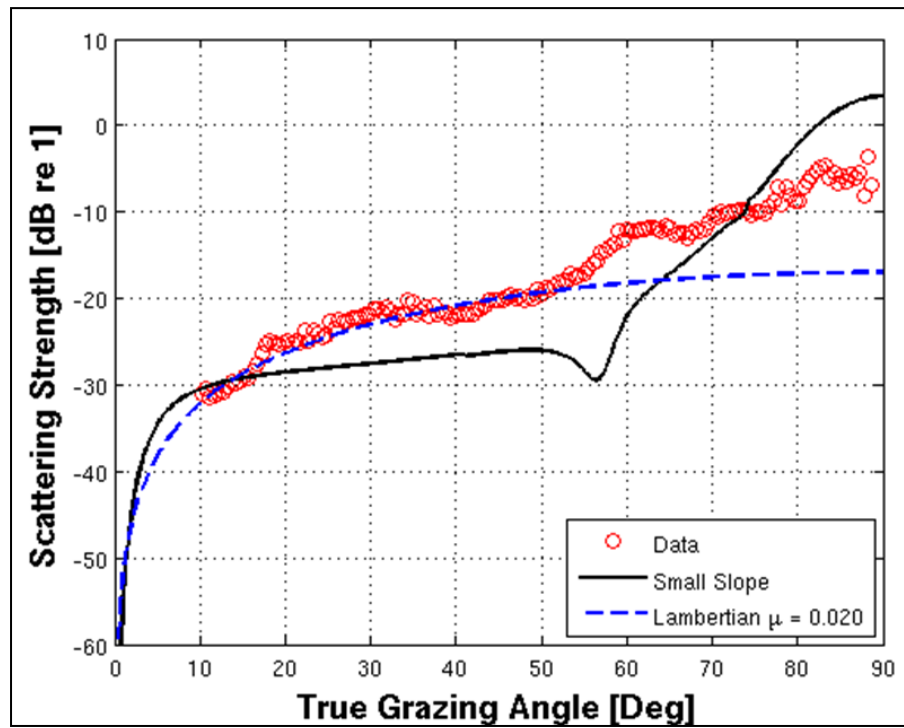SAS Image of Svaberg

Figure 2

Figure 3

IMPACT/APPLICATIONS

SAS image statistics research is providing an improved understanding of the environmental parameters that affect high-frequency imaging systems. This study is leading to methods for modeling and predicting these environmental effects that may be used to minimize their negative impact on detection and classification of targets on or near the seafloor in shallow water. Knowledge gained will help in the development of simulation tools, adaptive systems for sonar systems and rapid environmental assessment techniques for estimating environmental parameters for a given area.

TRANSITIONS

The models of that have been explored and developed are being incorporated when possible into the ARL-PSU Technology Requirements Model (TRM), a high fidelity, physics-based digital simulator. Discussions are also under way to include models into simulations of Synthetic Aperture Sonar being developed at NSWC-Panama City.

RELATED PROJECTS

A related ONR project (Grant N00014-10-1-0051) is Statistics of High-Resolution Synthetic Aperture Sonar Imagery: Physics-Based Speckle/Texture Analysis and Simulation managed by Jason Stack, code 321OE.

PUBLICATIONS

Lyons, A.P. and D.C. Brown, 2012, 'The impact of the temporal variability of seafloor roughness on Synthetic Aperture Sonar repeat-pass interferometry,' in press, IEEE J. Ocean Eng.

Johnson, S.F. and A.P. Lyons, 2012, 'Synthetic Aperture Sonar image statistics for resolution degraded multi-aspect imagery,' 11th European Conference on Underwater Acoustics, Edinburgh, Scotland.

Brown, D.C. and A.P. Lyons, 2012, 'Speckle statistics in synthetic aperture sonar imagery," 11th European Conference on Underwater Acoustics, Edinburgh, Scotland.

Lyons, A.P. and D.C. Brown, 2012, 'The impact of the temporal variability of seafloor roughness on Synthetic Aperture Sonar repeat-pass interferometry, 11th European Conference on Underwater Acoustics, Edinburgh, Scotland.

Olson, D.R. and A.P. Lyons, 2012, 'The effects of finite scattering area on validity criteria for scattering models,' 11th European Conference on Underwater Acoustics, Edinburgh, Scotland.

Lyons, A.P. and S.F. Johnson, 2011 'Estimating seafloor roughness using synthetic aperture sonar image statistics,' 162nd Meeting of the Acoustical Society of America, San Diego, CA, November.

Olson, D.R. and A.P. Lyons, 2011, 'Characterization and scattering measurements from rock seafloors using high-resolution synthetic aperture sonar,' The Journal of the Acoustical Society of America, 10/2011; 130(4):2349. DOI:10.1121/1.3654409